Growth of Roots and Root Hairs of Pine and Hardwood Seedlings in the Piedmont

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The relative ability of tree seedlings to develop a large root-absorbing system is found to be associated with ability to survive and grow under forest canopies.

THE regeneration of pine is a serious forestry problem in the Piedmont. In this region the authors have often observed that pine seed will germinate under a pine overstory and the resulting seedlings may for a time appear rather vigorous. Whenever a moderately intense drought occurs, however, most or all of the pine seedlings succumb presumably due to desiccation occasioned by their inability to absorb adequate moisture. Hardwood seedlings readily survive such droughts under a pine overstory and the ensuing stand eventually becomes composed almost wholly of hardwood species. Pines readily become established on cleared land if abandoned for agriculture. Pure stands of loblolly pine (*Pinus taeda* L.) or shortleaf pine (*Pinus echinata* Mill.) may result. The failure of pine regeneration without clearing of forest or abandonment of farm land has been attributed to differences in physiological reactions of pine and competing hardwood seedlings to decreased light intensity and decreased soil moisture which exist within the environmental complex of a closed stand (*9, 8, 6*). Chapman (*4*) has observed that pine seedlings grown in light are more resistant to drought than those grown in the shade. Oosting and Kramer (*9*) have indicated that pine can survive periods of low available soil moisture and even compete successfully with hardwoods provided that pine is not too heavily shaded. Under drought conditions rates of extensión of roots are of the greatest significance in making water available to seedlings. Oosting and Kramer have stated that survival and growth of pines require a light intensity which is high enough for them to produce enough food to develop root systems capable of absorbing the necessary water. Shoot-root ratios of loblolly pine seedlings, as well as root growth, are profoundly affected by shade. The senior author (*7*) found statistically significant differences in growth due to shading 2-year-old loblolly pine seedlings (in shade the second year only) and 3-year-old seedlings (shaded two years). Significant differences were found in height growth, dry weight of foliage, dry weight of stems, dry weight of roots, total dry weight, and shoot-root ratios. These findings further indicate that the greater rate of elongation of roots and a larger root system of pine which has not been shaded are the result of increased photosynthetic rate which results in greater availability of soil moisture in dry soil that has not reached the wilting percentage.

In addition to recognizing the differences in reaction of competing species to environmental factors it seemed desirable to compare root growth of competing seedlings in similar environments. The hereditary limitations on root growth need to be evaluated since internal physiological processes and plant conditions are also a function of these. Excellent quantitative studies have been made of water-absorbing surfaces of herbaceous plants by Pavlychenko (*10*), Dittmer (*5*), and others but very little attention has been focused on such studies for forest-tree seedlings in connection with the problem of competition.

METHODS

Seedlings of loblolly pine (*Pinus taeda* L.) and dogwood (*Cornus florida* L.) were grown from seed in boxes of soil in the greenhouse during the summer and autumn. The soil was kept well watered, but drainage was sufficient to prevent saturation. Roots of seedlings were washed free of soil under a water tap and preserved in a weak alcohol-formalin solution. Lengths of all roots of randomly selected seedlings of dogwood and loblolly pine were carefully measured with a centimeter scale. Lengths were converted for the various orders of roots into inches and the total length was obtained for each seedling in feet. Summation of measure-

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ments for one seedling of each species is given in Table 1. Roots of 1 additional seedling of dogwood and 3 additional seedlings of loblolly pine were measured and showed a similar root distribution pattern. The total length of roots of the second dogwood seedling was 305.98 feet while the root lengths of the other three pine seedlings were 7.69, 15.33, and 21.56 feet.

A further comparison was made of root systems of black locust (*Robinia pseudoacacia* L.) and loblolly pine. Seeds of both species were sown in culture boxes filled with soil rich in humus. The culture boxes were 12 inches square and 14 inches deep. After seedlings were well established, a centrally located seedling was selected for study and all others were removed. When seedlings had been grown to the age of 4 months in the greenhouse under favorable conditions the boxes were soaked in water. By a flotation process the soil was very carefully removed from the roots. Entire root systems were removed and preserved in a dilute solution of formalin-alcohol for counts and measurements. The entire root systems of two pine seedlings were measured but because of the great number of roots in the locust seedling a sample was drawn and the total root system estimated by the ratio of dry weight of total root system to total length. One primary root that appeared to be an average one was measured. Measuring was done under water since the smaller branch roots had a tendency to align themselves along the primary root when taken from the preservative solution. Data for the primary root of black locust and the entire root system of one pine seedling are given in Table 2. The sample root of locust that was measured comprised one-fifth of total dry weight; the total estimated length of the black locust root system was 1,068 feet. The additional pine seedling had a root distribution that was similar to the first with a total length of 6.2 feet.

In order to compare outdoor-grown 1-year-old loblolly pine and white oak (*Quercus alba* L.) seedlings, soil blocks 8″ x 8″ x 14″ which contained these seedlings were excavated from a forest near Durham, North Carolina. Soil was washed from the roots after the blocks were soaked in water. The larger roots could be measured with an ordinary 15-centimeter ruler but the majority of the roots required a binocular for accurate determination of length. Results of measurements on one seedling of each species are given in Table 2. The roots of one additional seedling for each species were measured and the differences between pine and oak were again rather marked. The length of roots of pine seedlings was 2.6 feet while for oak it was 5.1 feet.

Because of the importance of root hairs in absorption of water and nutrients it seemed desirable to sample root-hair frequency and calculate the absorbing surface on roots of pine and hardwood seedlings. According to Büsgen and Münch (*2*) there is a difference in persistence of root hairs. In some cases the root hairs persist on the entire branch system for the greater part of its length, while in other cases root hairs are active only a short time and soon shrivel and die. In this study root hairs on the upper portions of the primary roots were observed to be sloughing off along with sections of the epidermis. These root hairs are generally outgrowths of epidermal cells, but in conifers

TABLE 1.—ORDERS, NUMBERS, AND LENGTHS OF ROOTS OF ONE 6-MONTHS-OLD DOGWOOD AND ONE LOBLOLLY PINE SEEDLING GROWN IN THE GREENHOUSE IN ABSENCE OF COMPETITION

Order	Dogwood		Loblolly pine	
	Roots	Lengths	Roots	Lengths
	Number	*Centimeters*	*Number*	*Centimeters*
First	1	44.1	1	32.2
Second	93	859.7	71	187.5
Third	1035	2714.4	496	146.1
Fourth	1336	1357.0	199	21.2
Fifth	191	168.1	0	0.0
Sixth	1	0.6	0	0.0
Total	2657	5143.9	767	387.0
Length, feet		168.76		12.70

TABLE 2.—ORDERS, NUMBERS, AND LENGTHS OF GREENHOUSE-GROWN BLACK LOCUST AND LOBLOLLY PINE SEEDLINGS AND FOREST-GROWN WHITE OAK AND LOBLOLLY PINE SEEDLINGS

Order	Greenhouse-grown seedlings						Forest-grown seedlings					
	One primary root of black locust, 4 months old			Loblolly pine 4 months old			Loblolly pine one year old			White oak one year old		
	Roots	Av. length	Tl. length	Roots	Av. length	Tl. length	Roots	Av. length	Tl. length	Roots	Av. length	Tl. length
	No.	*Cms.*	*Cms.*	*No.*	*Cms.*	*Cms.*	*No.*	*Cms.*	*Cms.*	*No.*	*Cms.*	*Cms.*
First	1	41.00	41.0	2	12.70	63.50	4	8.75	35.00	1	25.00	25.00
Second	104	7.30	759.8	251	0.33	82.62	66	0.81	53.70	84	1.33	112.00
Third	2,340	1.08	2,522.0	163	0.09	14.85	78	0.18	14.20	108	0.90	97.00
Fourth	3,308	0.62	2,051.7	0	...	...	0	...	...	0	...	...
Fifth	1,276	0.52	653.7	0	...	...	0	...	...	0	...	...
Sixth	365	0.41	151.0	0	...	...	0	...	...	0	...	...
Seventh	20	0.38	7.5	0	...	...	0	...	...	0	...	...
	7,124		6,186.7	419		160.97	148		96.90	196		234.00
	Total length for locust seedling = 32,553.6 cm. = 1068 feet					5.3 ft.			3.2 ft.			7.7 ft.

the root hairs are developed from cells of the second or third layer.

To obtain material for a study of root hairs loblolly pine and black locust seedlings were grown in the greenhouse and when approximately 7 weeks old were removed and their roots were examined. The roots were hardened and preserved in a solution of formalin before they were measured. The pine root systems were characteristically poorly developed and their roots were confined to a short primary root and a few scattered, stubby laterals with no tertiary roots present. Black locust seedlings developed a comparatively extensive root system and possessed tertiary and secondary roots in abundance.

To determine the number of root hairs on each species numerous secondary and tertiary sample roots were randomly drawn from each system. The primary or tap root was cut into 1-centimeter lengths at intervals of 10 percent of the root length. Root types were kept separate so that data could be obtained on their relationship to root hairs. Roots were sectioned in a freezing microtome. The 75-micron-thick sections of each root type were well mixed so that there was no greater chance for sections of one particular root to be observed than the sections from any other root of the same type. Sections were removed for study with a dropper so selectivity was avoided and randomization was effected. The number, or absence, of root hairs was observed with a microscope and recorded. After observing more than one hundred sections of a particular root type for each species, the average number of root hairs was calculated per section. Sections were placed in a projector and drawings made of them. Primary root sections were enlarged 70 times and secondary and tertiary roots 180 times. Drawings of the root sections exclusive of root hairs were traced with a chartometer to permit calculations of average root diameter and surface area of roots. Each root-hair drawing was measured and the average surface area of each calculated. The root systems of 12 pine seedlings and 12 black locust seedlings were measured to obtain data for an average root system of each species population. With this information the number of root hairs, surface area of root hairs, and surface area of roots were obtained for entire root systems. Observations are given in Table 3.

Results and Conclusions

With absence of competition the average number of roots for dogwood seedlings 6 months old was about 3,000 while in loblolly pine of the same age the average was approximately 1,000. Although there was considerable variation in numbers of roots in individual seedlings it is significant that none of the pine seedlings had more roots than slightly over one-third of the mean for dogwood. In pine most of the roots were third-order roots but many second- and fourth-order roots were present. There were no roots for pine beyond the fourth order. The bulk of the roots for dogwood was in the third and fourth order but sixth-order roots were also found. Thus it is evident that dogwood had more branches and more roots. The total length of all roots of the dogwood seedlings was many times that of the pine seedlings.

Loblolly pine grown in the greenhouse for only 4 months had distinctly better root development than did one-year-old forest grown pine seedlings. Both groups had roots through the third order but the average number of the greenhouse grown seedlings far exceeded that of the one-year-old forest-grown seedlings. In the greenhouse the total length of all roots was over 5 feet per seedling while it was approximately 3 feet for those grown in the forest. The forest grown white oak seedlings which were also 1-year old had distinctly better root systems than did the forest-grown pine. The total number of roots was slightly greater in oak and furthermore the total length was considerably greater. Greenhouse-grown, 4-month-old black locust seedlings had approximately 17 times as many roots and about 170 times more root length than did loblolly pine seedlings of the same age.

The findings of this study suggest that in evaluating the problem of pine regeneration and competition the inherent capacity for root growth needs to be considered in addition to species differences in physiological reactions to the environment of competition. Tables 1, 2, and 3 indicate that the number of roots produced, the total length of the root system, and the rates of elongation of roots are considerably less for pine seedlings, even without competition. In another study (*7*) it was found that 3-year-old white oak seedlings had a greater dry weight of foliage than did loblolly pine seedlings of the same age but in oak there was far more root per unit of shoot (dry weight basis) than in loblolly pine. The reduced rate of elongation of pine roots is in keeping with the fact that the senior author (*7*) found that under conditions of optimum soil moisture and full light intensity (approximately 10,000 foot candles) absolute photosynthetic rates were much greater for oak seedlings than for pine seedlings. Kramer and Decker (*8*) have also indicated that rates of photosynthesis in pine are considerably less than those of competing hardwood species. Coile (*3*) compared statistically the weight and length of roots of 1-year-old forest-grown loblolly pine and

Table 3.—Numbers of Roots, Root Lengths, Surface Area of Roots, and Surface Area of Root Hairs of 7-weeks-old Black Locust and Loblolly Pine Seedlings. Data Represent Averages for 12 Seedlings of Each Species

Order	Root length	Root surface area	Root hairs	Root hair surface area
	Centimeters	*Square centimeters*	*Number*	*Square centimeters*
		Black locust		
Primary	16.20	3.4466	1,166	3.6346
Secondary	115.62	15.7167	8,321	25.2172
Tertiary	30.60	3.1151	2,081	5.1759
Total	162.42	22.2784	11,568	34.0277
			520 root hairs per sq. cm.	
		Loblolly pine		
Primary	6.45	1.7341	215	0.7973
Secondary	5.93	0.9683	371	2.0770
Total	12.38	2.7024	586	2.8743
			217 root hairs per sq. cm.	

white oak seedlings. He found the average length of the primary root of the oak seedlings to be more than four times as great as that for pine. Lateral roots were eight times as long for white oak as for loblolly pine seedlings and there was significantly more root growth per unit of shoot growth in oak seedlings than in pine. The average weight of root systems of white oak seedlings was 100 times greater than that of loblolly pine seedlings. Toumey (*11*) found that oak and hickory seedlings developed a 10- to 15-inch taproot the first year and that red cedar and tulip poplar seedlings produced a deep, much-branched root system during the first year. Billings (*1*) has reported that seedlings of oak, hickory, and tulip poplar in a 31-year-old shortleaf pine stand in the North Carolina Piedmont had uniformly developed root systems when young. Billings has stressed the importance of the deeply penetrating root systems of hardwood seedlings in passing through and beyond the zone of greatest pine root competition during the first year. He also reported highly developed, much-branched root systems for seedlings of red maple and dogwood. The independent findings of these investigators also indicate that the inherent capacity for root growth of the species involved is an important factor in competition in forest stands.

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